Predictive Modeling of Tool Wear in Hard Turning

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Introduction and motivation

- Hard turning process is defined as single point turning of materials harder than 50HRc and differs from conventional turning in:
  - Workpiece material property
  - Chip formation mechanism
  - Cutting tool required
  - Cutting condition applied
- It offers possible benefits over grinding process:
  - Lower equipment costs
  - Shorter setup time
  - Reduced process steps
  - High material removal rate
  - Better surface integrity
  - Elimination of cutting fluid

Challenging issues in hard turning technology

- The top issues to be solved in hard turning process:
  - Tool wear <Our researching interest>
  - Form accuracy
  - Surface integrity
  - Economic consideration

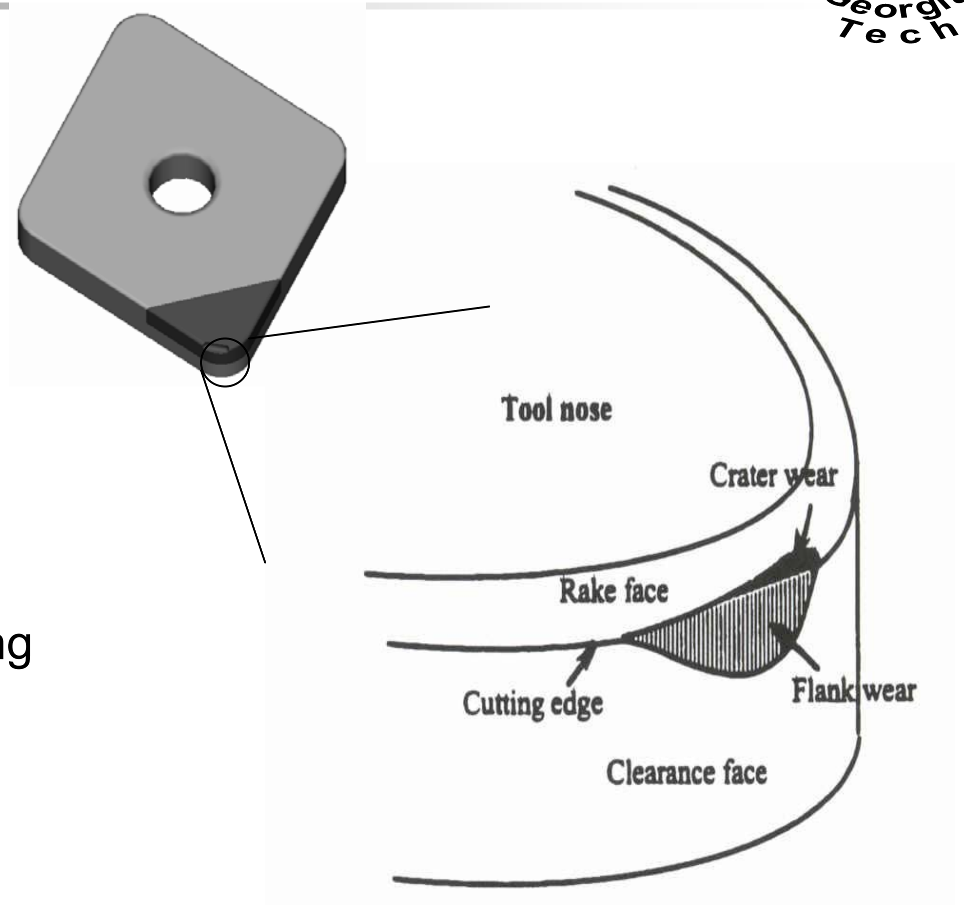
- Why tool wear:
  - High cost of CBN cutting tool, which is generally applied in hard turning
  - Cost of down-time for tool changing affects the economic justification of hard turning
- What to do about tool wear:
  - To find a relationship defining tool wear rate as the function of cutting condition and tool geometry for a given tool/work combination in hard turning

Factors influencing wear rate

- Tool material's composition
  - CBN particle size and CBN content
  - Binder materials
  - Applied coating material and coating thickness
- Cutting condition
  - Feedrate
  - Depth of cut
  - Cutting speed
- Tool geometry
  - Rake angle for up-sharp tool
  - Chamfer length and angle, rake angle for chamfered tool
  - Hone radius, rake angle for honed tool
  - Tool nose radius

Tool wear in hard turning

- Wear patterns in metal cutting
  - Crater wear
  - Flank wear
  - Depth of cut notching
  - Thermal shock crack
  - Nose wear
  - Chipping
  - Tool breakage
  - Built-up edge
- Wear mechanisms in metal cutting
  - Abrasion
  - Adhesion
  - Attrition
  - Fatigue
  - Dissolution/diffusion
  - Tribochemical process



Wear pattern in metal cutting

Tool wear in hard turning (cont'd)

Main wear patterns in hard turning

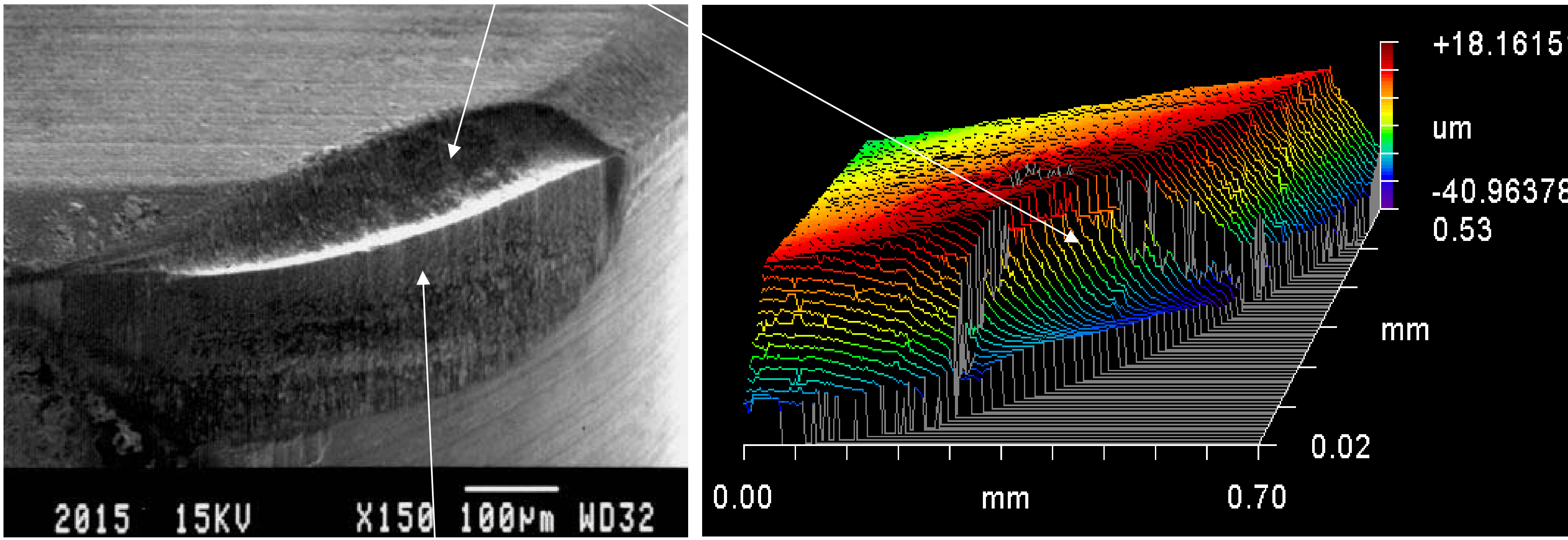
- Crater wear
- Flank wear
- Chipping: happens in aggressive cutting conditions
- Flank wear and crater wear are our interests in this study

Main wear mechanisms in hard turning

- Abrasion: due to cementite and CBN particle (if have in high CBN tool) (Narutaki, *et al*., 1979; Davies *et al*., 1996)
- Adhesion: due to high temperature/stress along the tool/chip and tool/workpiece interfaces (Hooper, *et al*., 1988; Chou, 1994; Davies *et al*., 1996)
- Diffusion: binder material is not stable with iron due to high temperature (Narutaki, *et al*., 1979; Konig, *et al*., 1993)
- Tribochemical process: no convincible evidence yet
- Abrasion, adhesion, and diffusion are considered as basic mechanisms here

Objective of this research

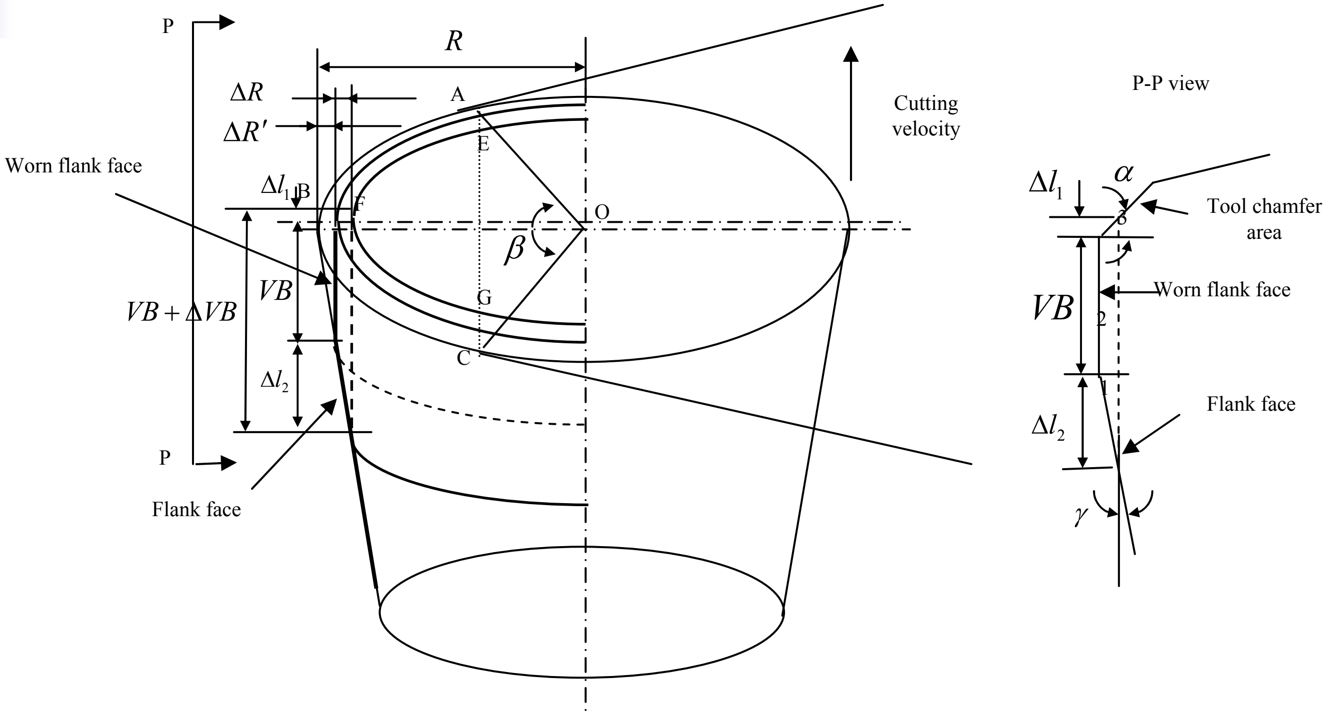
Crater wear



Flank wear

⇨ To develop a scientific, systematic, and reliable methodology to predict <u>the tool flank/crater wear rates</u> based on cutting condition and tool geometry for given tool and workpiece material properties.

Modeling of flank wear rate



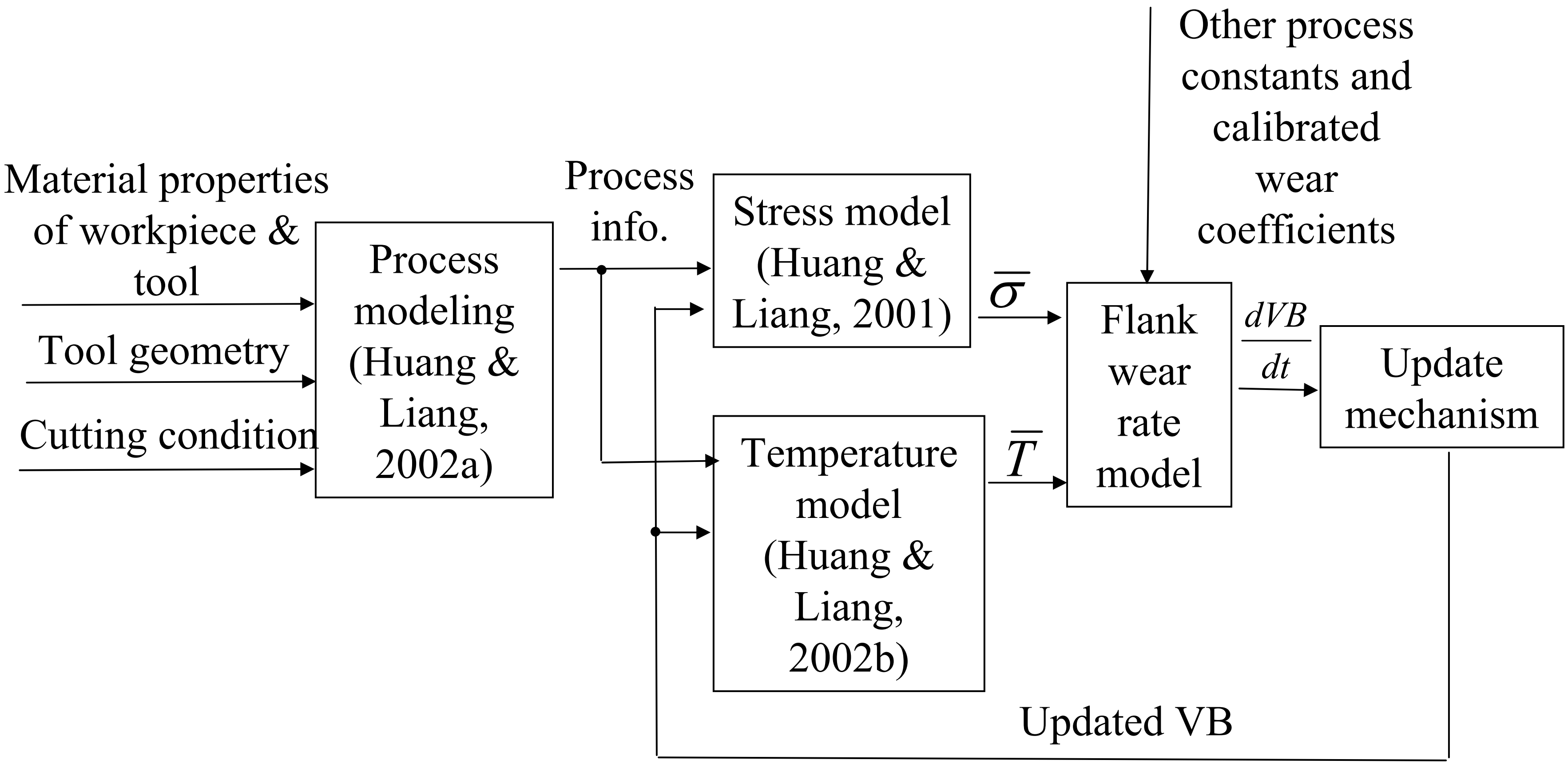
$$\frac{dVB}{dt} = \frac{(\cot\gamma + \tan\alpha)R}{\left[VB\left(R - VB\tan\gamma\right)\right]}\left\{K_{abrasion}K\left(\frac{P_a^{n-1}}{P_t^n}\right)V_c VB\overline{\sigma} + K_{adhesion}e^{aT}V_c\overline{\sigma} + K_{diff}\sqrt{V_c VB}e^{-\frac{K_Q}{T+273}}\right\}$$

Abrasion

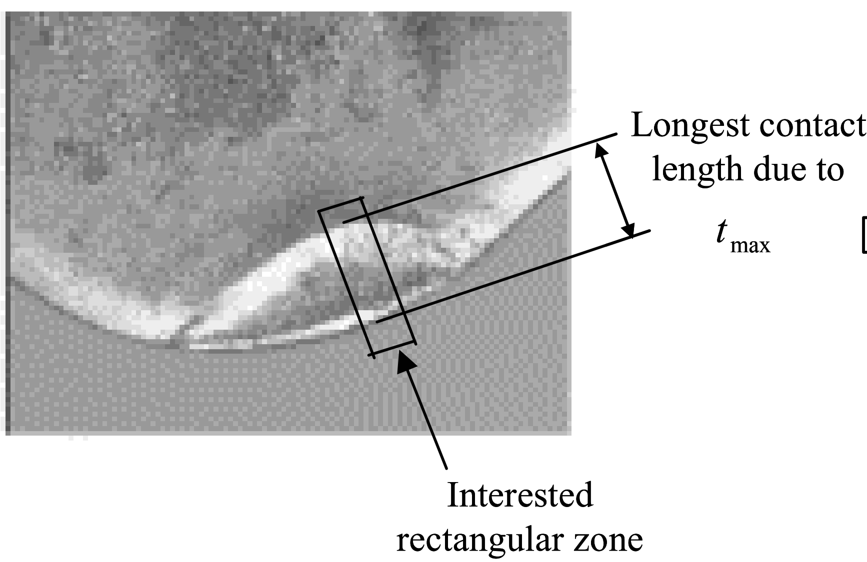
Adhesion

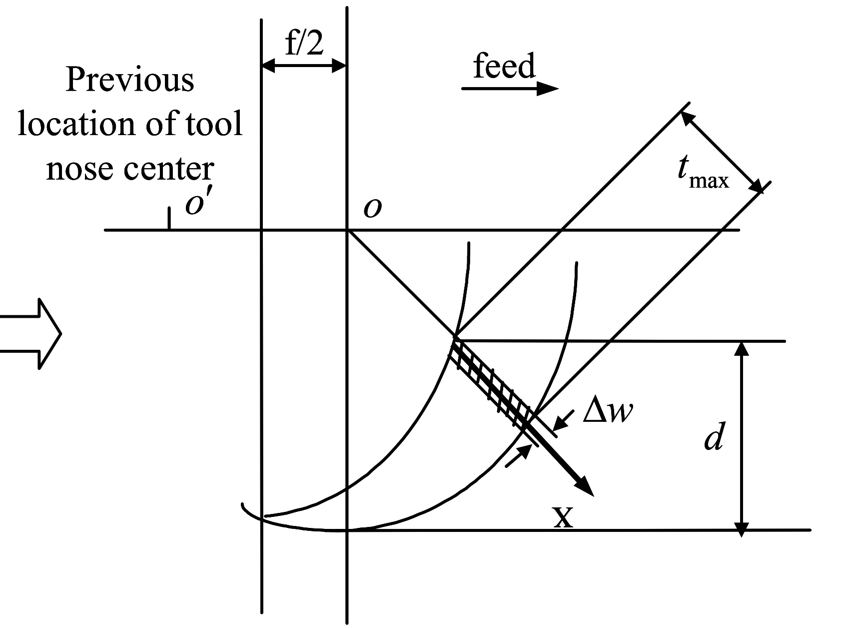
Diffusion

Modeling of flank wear rate (cont'd)



Modeling of crater wear rate





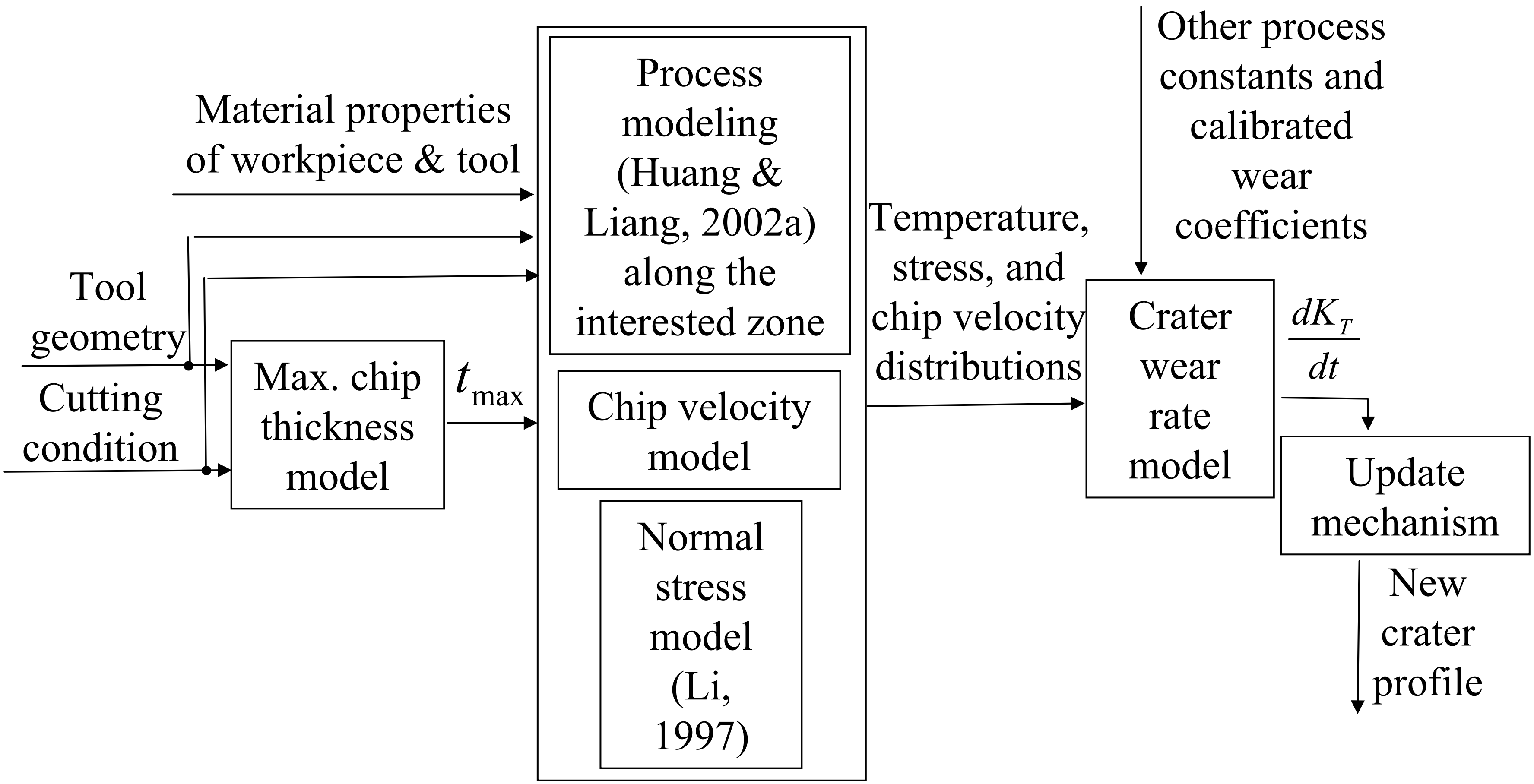
$$\frac{dK_T(x)}{dt} = K_{abrasion}K\left(\frac{P_a(x)^{n-1}}{P_t(x)^n}\right)V_{chip}(x)\sigma(x) + \frac{1}{h}K_{adhesion}e^{aT(x)}V_{chip}(x)\sigma(x) + K_{diff}e^{-\frac{K_Q}{T(x)+273}}\sqrt{V_{chip}(x)}\,\frac{(\sqrt{x+\Delta x}-\sqrt{x})}{\Delta x}$$

Abrasion

Adhesion

Diffusion

Modeling of crater wear rate (cont'd)



Calibration & validation of wear rate models

- Calibration of wear rate model

  $K_{abrasion}, K_{adhesion}, a, K_{diff}, K_Q$ need to be calibrated

  Those coefficients depend on tool/workpiece combination.

- Calibration steps
  - Optimize the coefficients of wear rate model by minimizing the least square error between predicted and measured flank wear rates for three cutting conditions (v=1.520m/s, f=.0760mm/rev, doc=.203mm; v=2.29m/s, f=.168mm/rev, doc=.203mm; v=1.520m/s, f=.0760mm/rev, doc=.102mm;) (Huang and Liang, 2002c)
- Validation steps
  - Validate the flank wear rate model based on seven cutting conditions (Huang and Liang, 2002c)
  - Validate the crater wear rate model based on three cutting conditions (Huang and Liang, 2002d)

Calibrated wear rate models

- Tool material: Kennametal KD050
- Workpiece material: hardened 52100, 62HRC

$$\frac{dVB}{dt} = \frac{(\cot\gamma + \tan\alpha)R}{\left[VB\left(R - VB\tan\gamma\right)\right]}$$

$$\times\left\{0.0295K\left(\frac{P_a^{n-1}}{P_t^n}\right)V_c VB\overline{\sigma} + 1.4761\times10^{-14}e^{9.0313\times10^{-4}T}V_c\overline{\sigma} + 5.7204\times10^{6}\sqrt{V_c VB}e^{-\frac{20460}{T+273}}\right\}$$

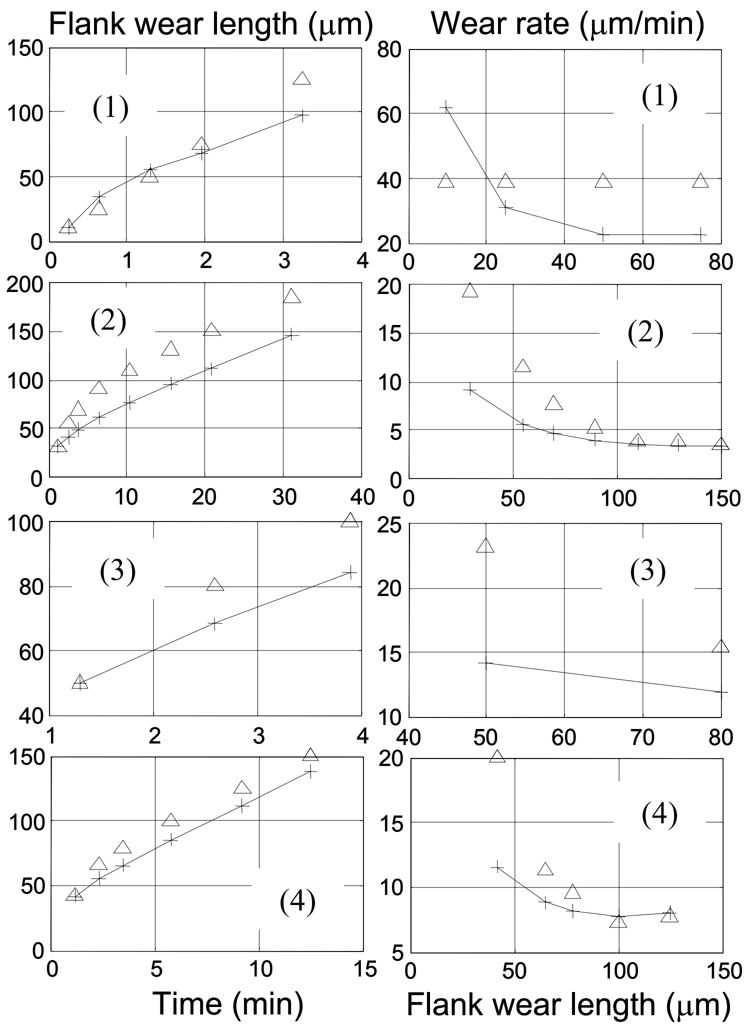
$$\frac{dK_T(x)}{dt} = 0.0295K\left(\frac{P_a(x)^{n-1}}{P_t(x)^n}\right)V_{chip}(x)\sigma(x)$$

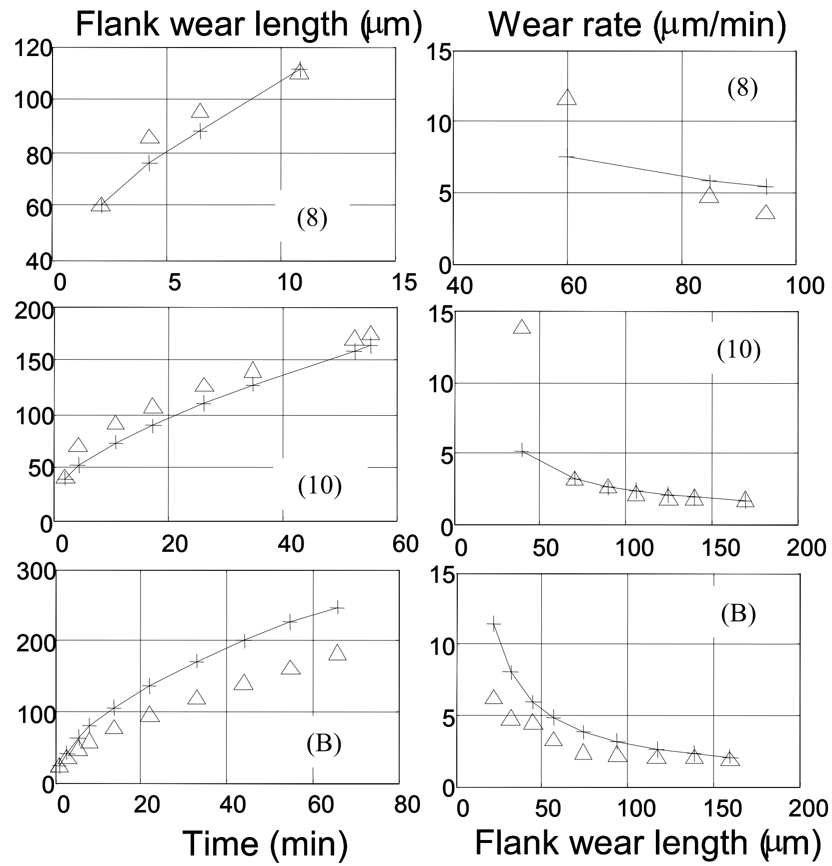
$$+1.4761\times10^{-14}e^{9.0313\times10^{-4}T}\frac{1}{h}V_{chip}(x)\sigma(x)$$

$$+5.7204\times10^{6}e^{-\frac{20460}{T+273}}\sqrt{V_{chip}(x)}\frac{(\sqrt{x+\Delta x} - \sqrt{x})}{\Delta x}$$

Validation of flank wear rate model

Flank wear progression



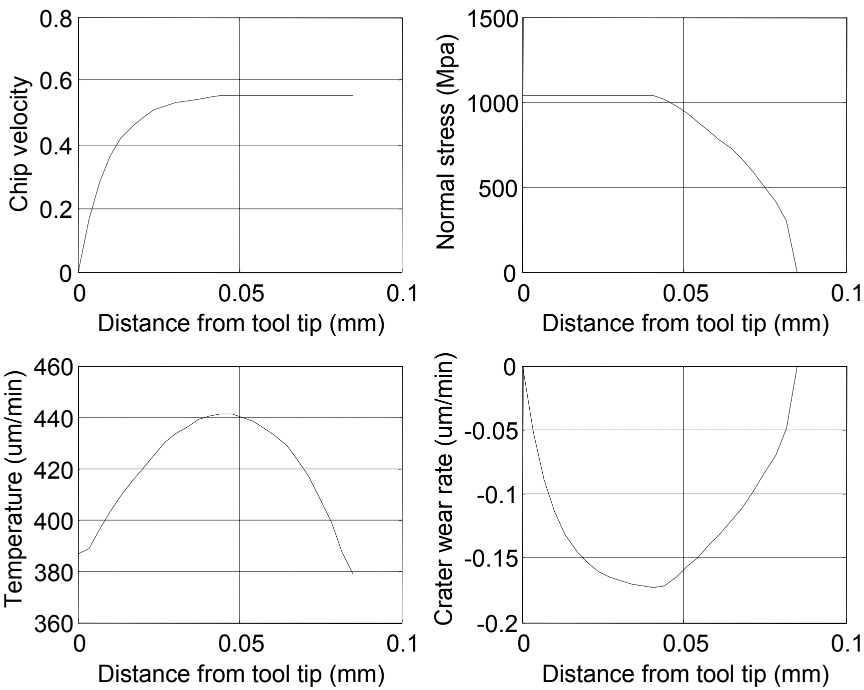


Solid line: predictions

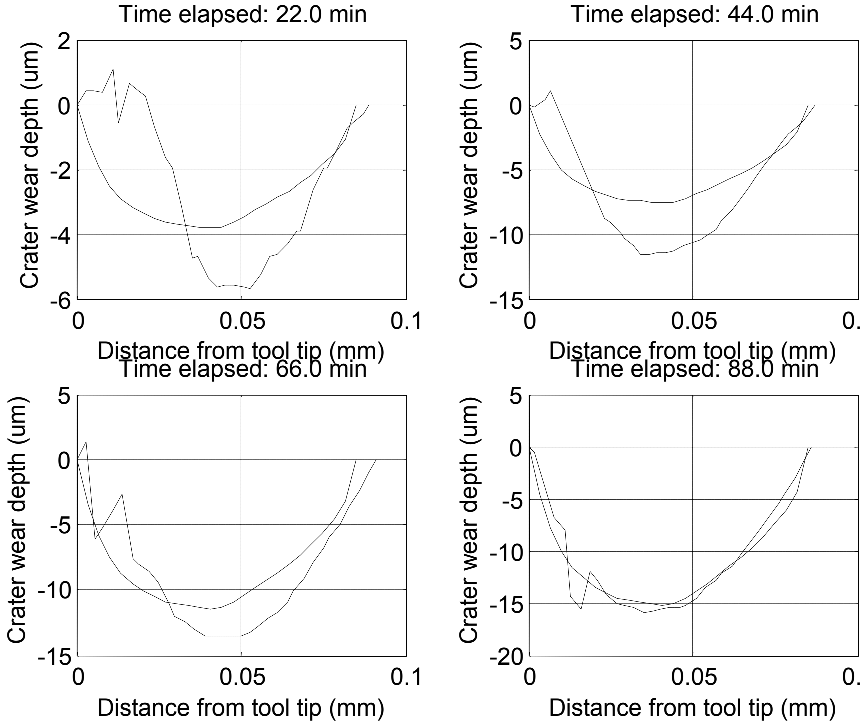
Triangular: measurements

Validation of crater wear rate model

Process information & crater wear rate



Crater wear progression



Solid line: predictions; dash line: measurements

Cutting conditions:

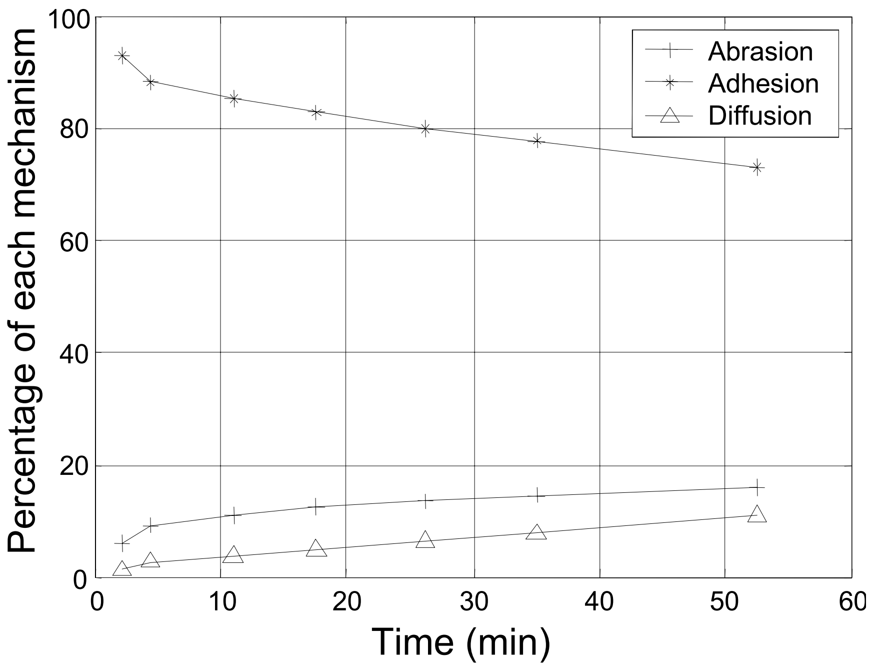
cutting speed: 1.52 m/s, feedrate: 0.076 mm/rev, depth of cut: 0.102 mm

Summary:

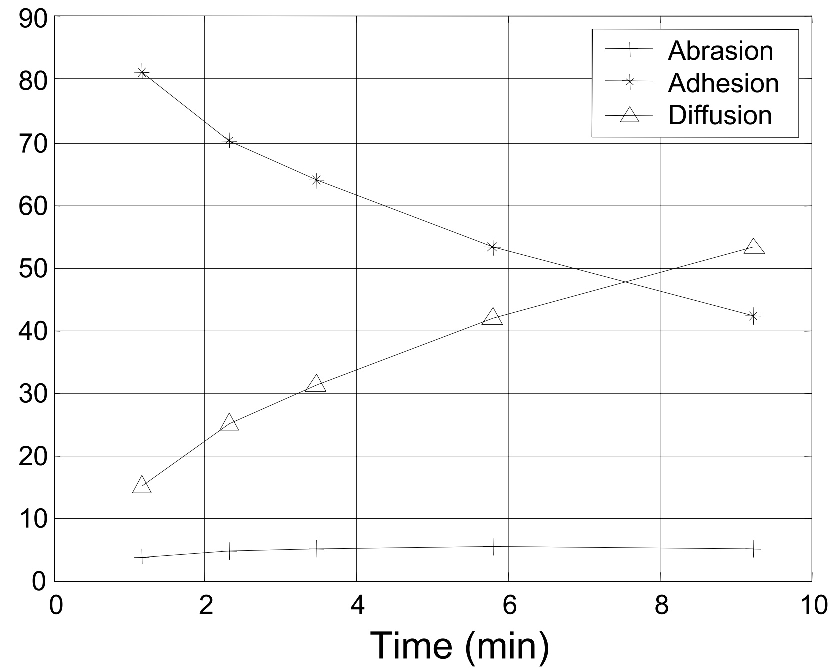
- Abrasion, adhesion, and diffusion in hard turning are considered as the main wear mechanisms for the progressive tool wear. The total tool wear rate is contributed from abrasion, adhesion, and diffusion mechanisms.

- The progressive tool flank/crater wear can be modeled as the function of cutting condition and tool geometry for a given tool/workpiece combination in a reasonable accuracy in hard turning.

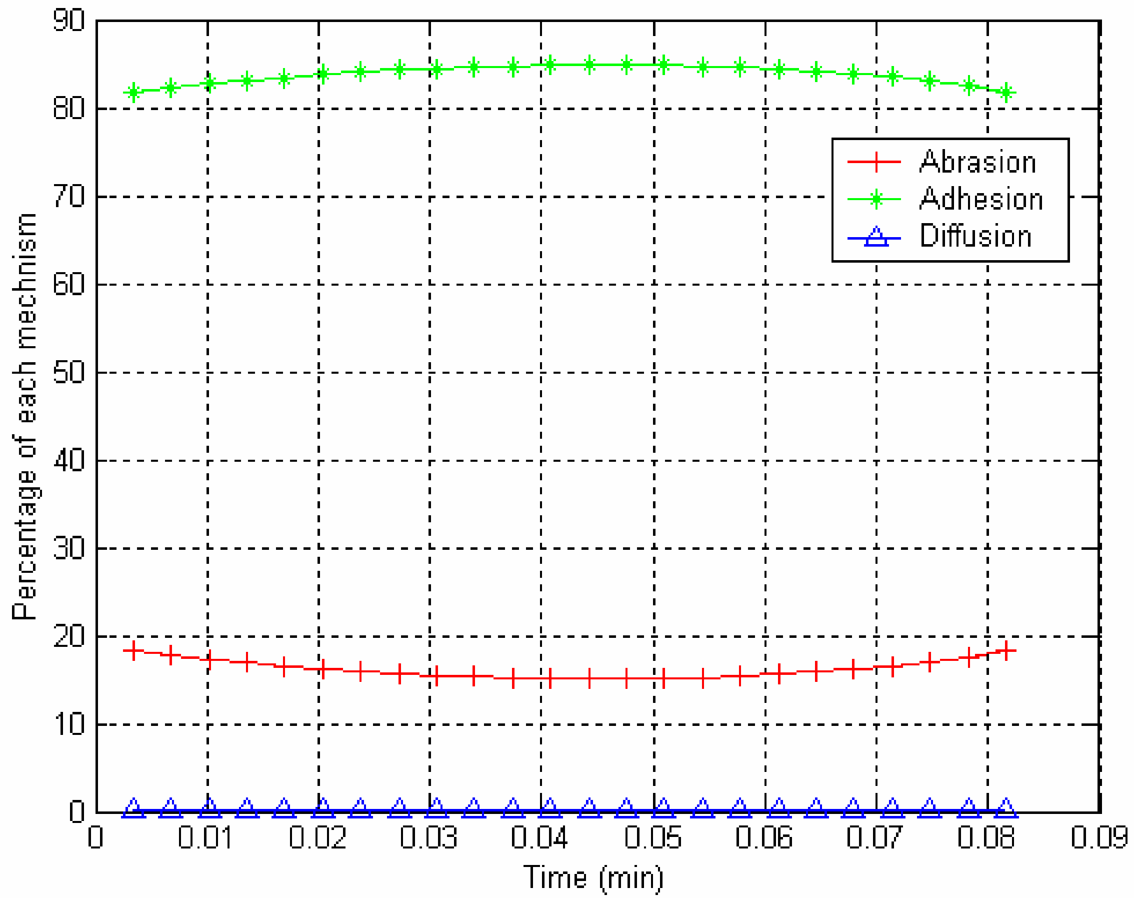
Questions?



General cutting condition (#10)

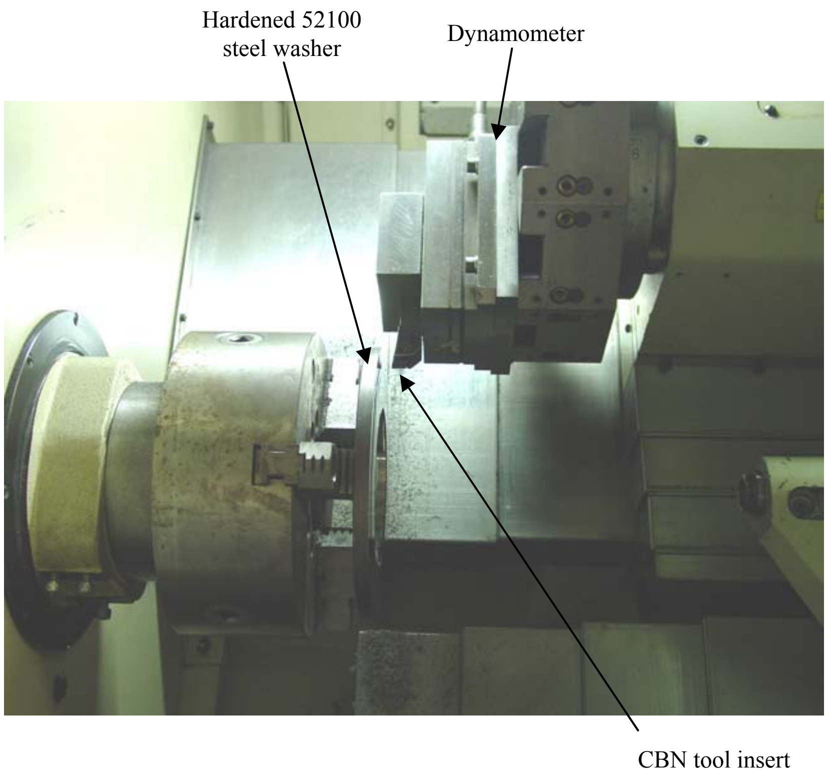


Aggressive cutting condition (#4)



90
80
70
60
50
40
30
20
10
0
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
Percentage of each mechnism
Time (min)
Abrasion
Adhesion
Diffusion

Pin-on-disk



Goal: to identify the wear coefficients under semi-sliding conditions without the effect of diffusion wear.